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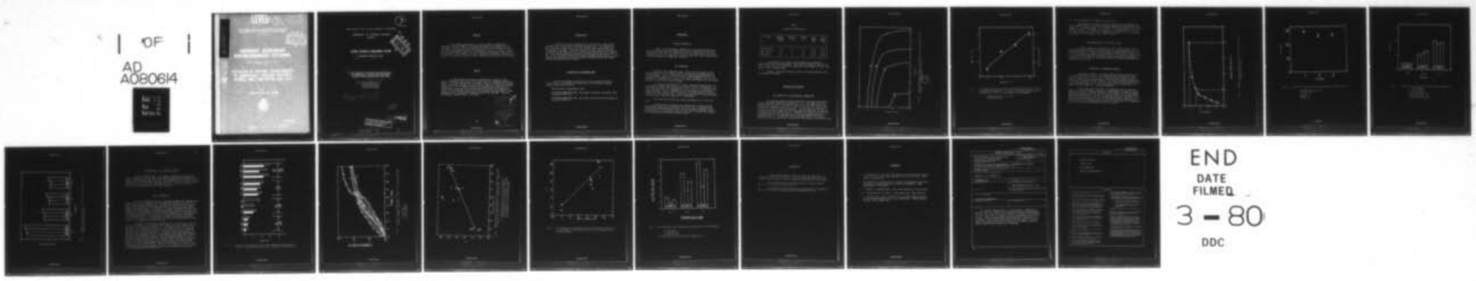

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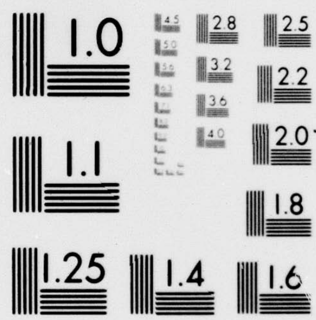
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# DEFENCE RESEARCH ESTABLISHMENT OTTAWA

9 TECHNICAL NOTE NO. 79-30

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# EVALUATION OF CRANKING CHARACTERISTICS OF COMMERCIALLY AVAILABLE BATTERIES BETWEEN ROOM TEMPERATURE AND -40°C.

by

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## ABSTRACT

The cranking characteristics of three brands of commercially available batteries (GROUP 24) were measured between room temperature (RT) and -40°C. They were fully recharged at RT before each discharge which was carried out at constant current corresponding to the 3C to 4C rates. Under the same experimental conditions, the behaviour on discharge of these batteries was found to be very similar. The only significant differences observed concerned the increase in internal battery temperature resulting from a discharge.

## RÉSUMÉ

Le comportement en décharge d'accumulateurs au plomb de trois marques différentes (groupe 24) a été étudié entre la température ambiante et -40°C. Ils étaient préalablement pleinement chargés à la température ambiante avant de subir une décharge à courant constant dans une fourchette de valeurs variant de 3 C à 4 C. Dans des conditions expérimentales identiques, le comportement en décharge s'est avéré identique pour tous les accumulateurs testés. Des différences significatives ont cependant été observées en termes d'élévation de la température interne résultant de la décharge. Elle est généralement comprise entre 1 et 2°C/min.

## INTRODUCTION

Vehicles are used by Canadian Forces in the Arctic where weather conditions may be very severe, especially during winter. The temperature may often drop to values as low as -40°C and may cause some problems with the starting of engines. The energy required to start an engine increases as temperature decreases (1) but the capacity and power which can be supplied by a fully charged lead-acid accumulator decreases drastically below -20°C (2). To more thoroughly define the problem, cranking characteristics of three commercially available batteries were measured between RT and -40°C under a constant discharge rate of 3C and 4C.

## OBJECTIVES OF THE PRESENT WORK

Test the discharge characteristics of the following batteries (2 per brand) in the temperature range from RT to -40°C with a constant cranking current from 3C to 4C:

- ESB Red Camel Low Maintenance (LM);
- GOULD MAINTENANCE FREE (MF), Pb/Sb grids in positive electrodes, Pb/Ca in negative ($Sb^+/Ca^-$);
- GOULD MAINTENANCE FREE (MF), Pb/Ca grids in both positive and negative electrodes ($Ca^+/Ca^-$).

## EXPERIMENTAL

### BATTERY PREPARATION

Prior to all discharges, regardless of the discharge temperature, the wet batteries were fully charged at RT under a charging rate of 0.05C. It should be noted that the relative density of sulphuric acid in the fully charged batteries was 1.28 at RT. The size, weight and other characteristics of these batteries are summarized in Table 1.

### TEST PROCEDURE

Initially, two (sometimes three) values of reserve capacity (RC) were determined at RT in order to reduce the influence of memory effect on further results. The RC is defined by North American manufacturers as the discharge time in minutes to a 1.75 V/cell cut-off voltage at a rate of 25A. However, RC is quoted in this report in Ah rather than minutes for a discharge at 25A to a 1.75 V/cell cut-off voltage.

The battery was subjected to further charge-discharge cycles at RT to determine cranking characteristics at 3C and 4C rates. In addition, the 2 RED Camel batteries were discharged at 210A ( 3.3C). The accumulators were fully recharged at RT at a charging rate of 0.05C between two consecutive cranking periods. Several cycles were done at RT while terminal voltage and current were recorded with time. During these experiments, a cut-off voltage of 6V was used to mark the completion of a discharge.

RT cycles were followed by several discharges at 0°C, -20°C and -40°C.

Internal battery resistance was measured with a Hewlett-Packard milliohmmeter Model No. 4328 (1000 Hz) before and after a discharge while a Fluke Digital Multimeter Model 8000 was used to measure terminal voltage. In addition, the acid temperature near the liquid/air interface was recorded with a thermistor probe during cranking periods.

TABLE 1

Battery Characteristics

| Source | Nominal Capacity (Ah) | Number of cells | Plates/ cell | Dry Weight (kg) | Wet Weight (kg) |
|---|---|---|---|---|---|
| Gould $Ca^+,Ca^-$ | 70 | 6 | 13 | 14.06 | 19.50 |
| Gould $Sb^+,Ca^-$ | 70 | 6 | 13 | 13.38 | 19.23 |
| RED CAMEL | 64 | 6 | 13 | 12.70 | 19.96 |

The batteries were charged and discharged after temperature equilibration with the surroundings. They were cold soaked at rest at 0°C, -20°C or -40°C in a cold chamber and removed from the chamber for only a few minutes before cranking tests.

Finally, the reserve capacity values at RT were determined after low temperature cycling.

## RESULTS AND DISCUSSION

### THE INFLUENCE OF THE SURROUNDING TEMPERATURE

The discharge plateau voltage and capacity decrease significantly as the surrounding temperature decreases (Fig. 1). For example, the discharge curves show that the terminal voltage of the Red Camel battery after one minute of cranking at 192A is 11, 10.5, 9.8 and 7.95V for temperatures of 20°C, 0°C, -20°C and -40°C respectively. It is evident that the rate of decrease in battery voltage with decreasing ambient temperature accelerates at temperatures below -20°C (Fig. 1). Therefore, the capacity and the electrical work done by the system decrease as the surrounding temperature decreases (Fig. 2). The behaviour of the Red Camel battery is a typical example: the electrical work and capacity are 0.0465 kWh and 5.5Ah respectively

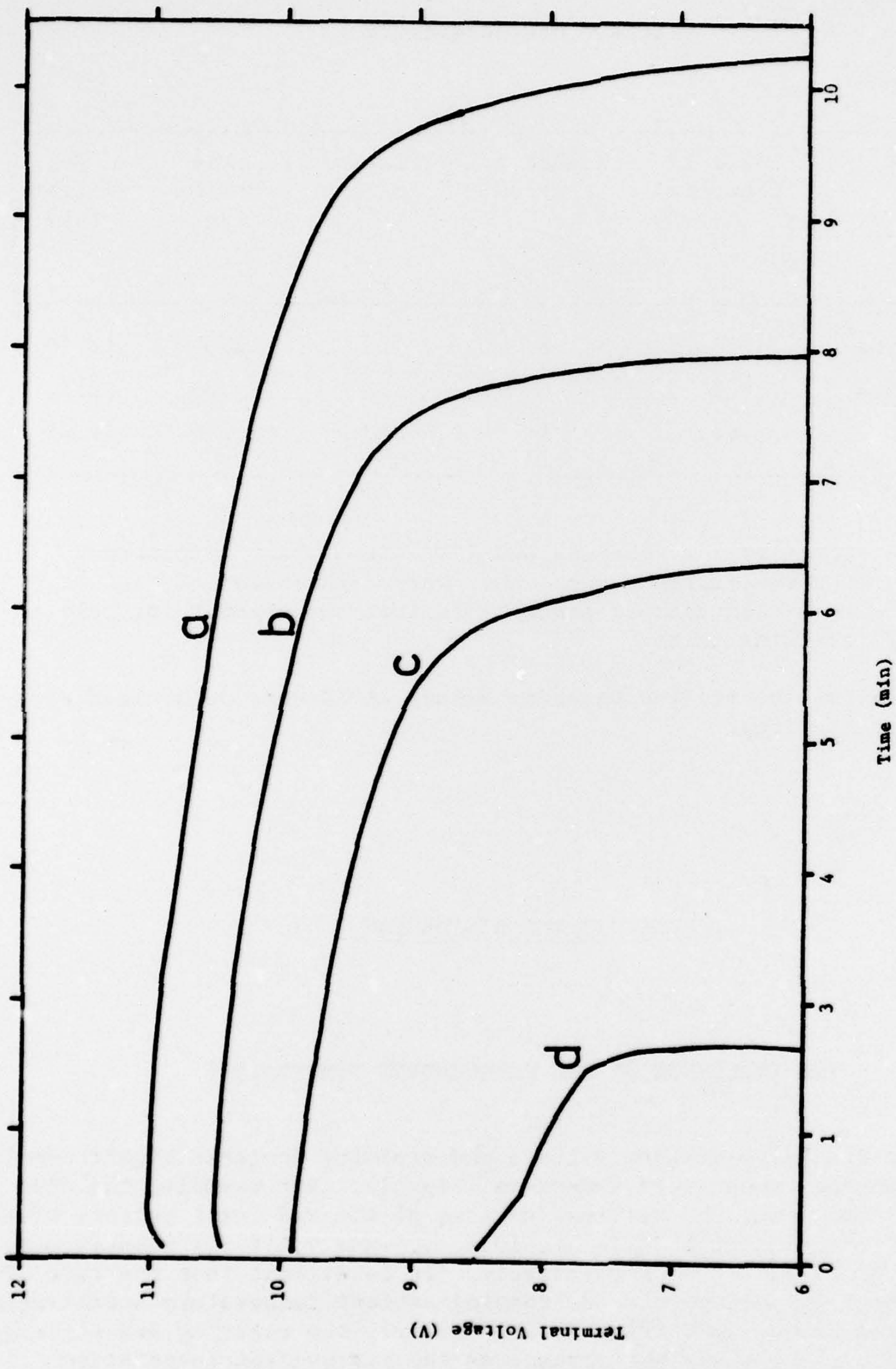


Fig. 1. Typical discharge curves for an initially fully charged Red Camel Battery. Cranking current: 192A (3C)
a: +20°C
b: 0°C
c: -20°C
d: -40°C.

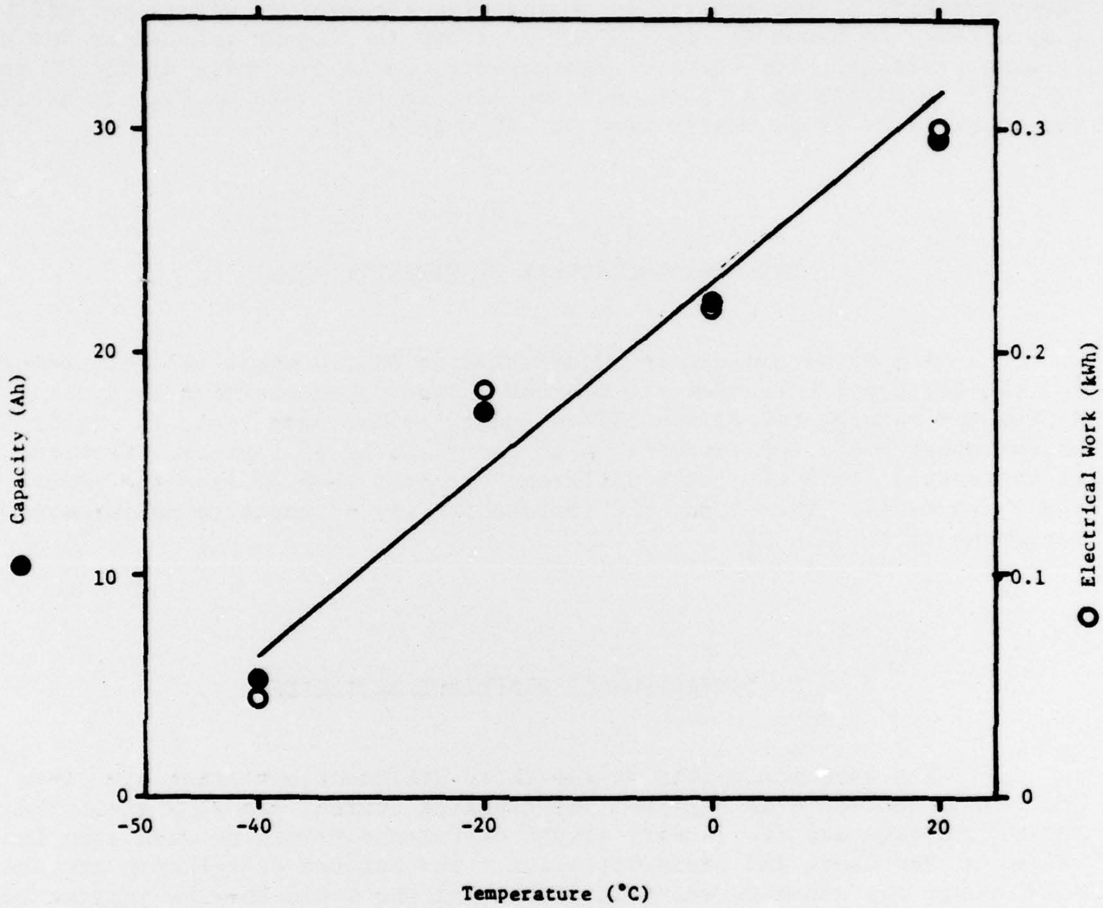


*Fig. 2. The capacity and the electrical work done by the Red Camel battery at different temperatures. Note that battery was previously fully charged and each value is the average of 3 measurements.*

*Cranking current: 192A (3C)*
*Cut-off Volt: 6V*

at - 40°C as compared to 0.3 kWh and 29.5Ah at RT.

Each capacity and each electrical work value were determined from three cranking curves at a given surrounding temperature with a cut-off voltage of 6V. As shown in Fig. 3, the capacity is closely related to the cut-off terminal voltage. For example, the capacity for a discharge at the 3C rate at -20°C is 17.5Ah to a 6V cut-off compared to only 14Ah at 9V. In addition, the capacity at 9V is nearly zero at -40°C (Fig. 1).

## THE REPRODUCIBILITY OF CAPACITY VALUES

A typical example is illustrated in Fig. 4 where capacity values for two Red Camel batteries are plotted versus the corresponding cycle. The difference between two values corresponding to the same cycle is within 3%. On the other hand, the capacity value decreases by 9% (approx.) from the first to the second cycle while the difference is less than 5% from the second to the third cycle. Therefore, the reproducibility of capacity measurements is estimated to be 3% - 9%.

## COMPARISON OF DIFFERENT BATTERIES

The capacity values of the three different batteries are given at 0°C, -20°C and -40°C in Fig. 5. The cranking current was 210A while the cut-off voltage was 6V. A very slight difference exists between capacity values of Red Camel and Gould batteries. The largest differences appears at -20°C where the capacity value is 13.6Ah for the Gould Sb+/Ca- against 10.1Ah for the Red Camel (Fig. 5). It should be noted that the capacity of each battery is very low at -40°C, 4.5Ah approximately.

On the other hand, the value of the apparent battery resistance (ABR) of the fully charged accumulators is approximately the same at a given temperature (Fig. 6). However, the ABR of Gould Sb+/Ca- is slightly higher (1mΩ) at each temperature. The ABR is strongly affected by the temperature and shifts from 5.5 to 12.4-mΩ as the temperature decreases from RT to -40°C. This is mainly attributed to a loss in acid conductivity as temperature decreases but if ice is formed inside the pores of the plates at low temperature (3, 4), this also would increase the value of the ABR.

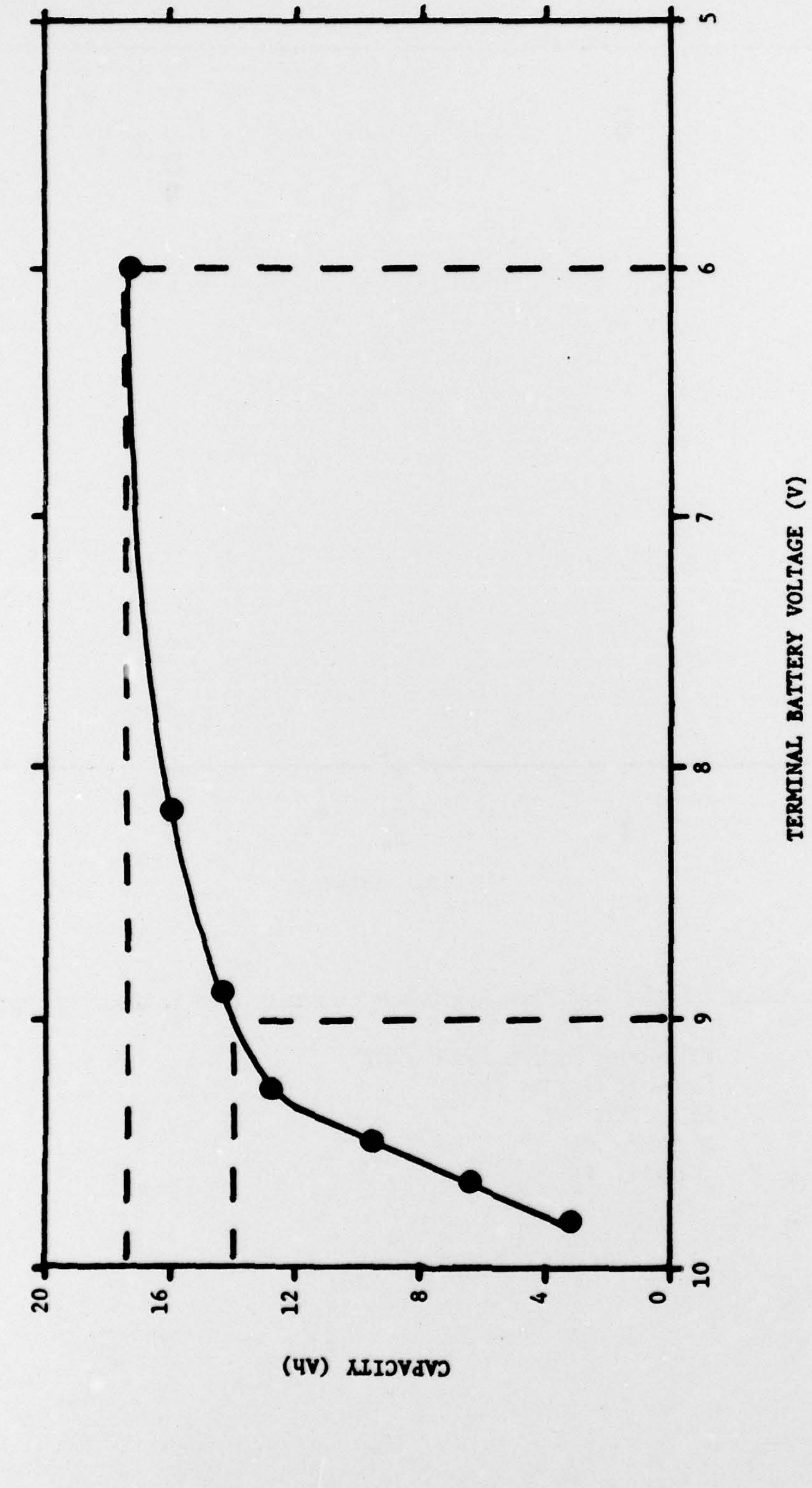


*Fig. 3. Capacity of the Red Camel battery versus cut-off voltage Cranking current: 192A.*

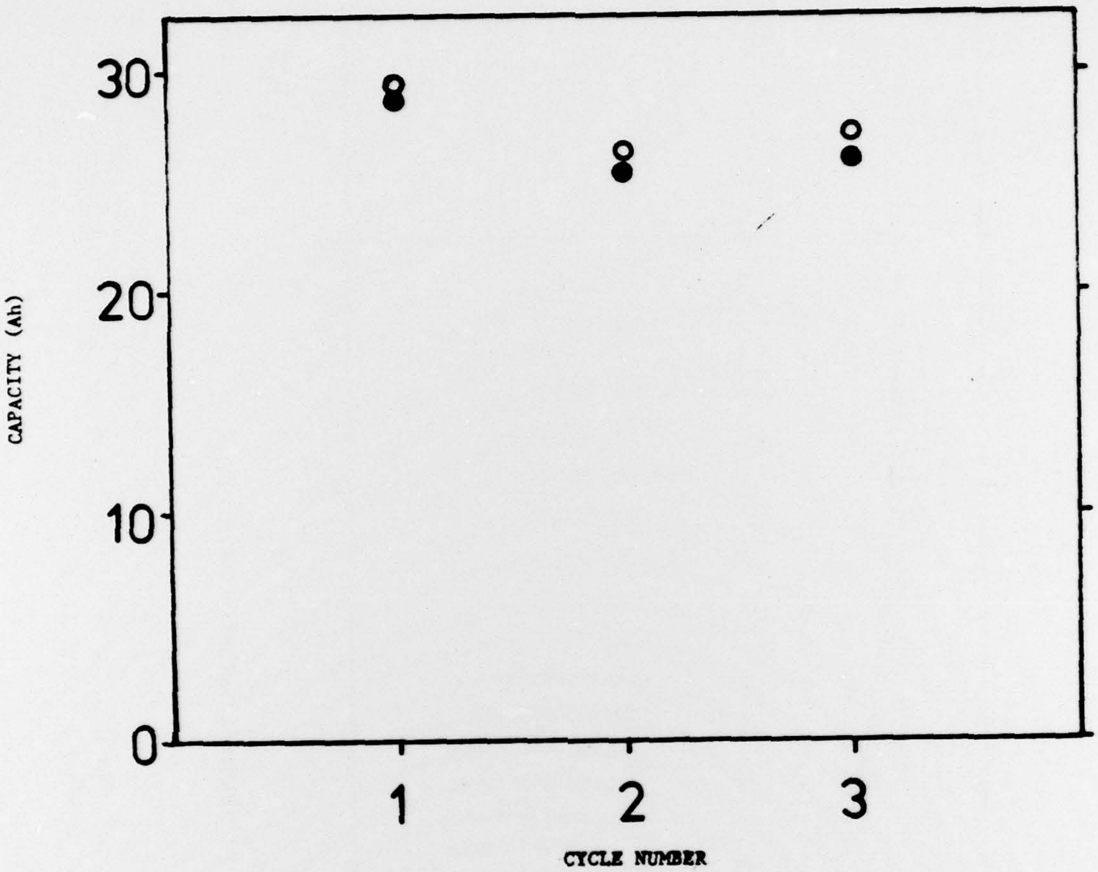


*Fig. 4. Capacity of the Red Camel Battery versus the number of cycles*

*Cranking Rate: 192A (3C)*
*Cut-off Volt: 6V*
*T: -20°C*
*● Batt. #1*
*0 Batt. #2*

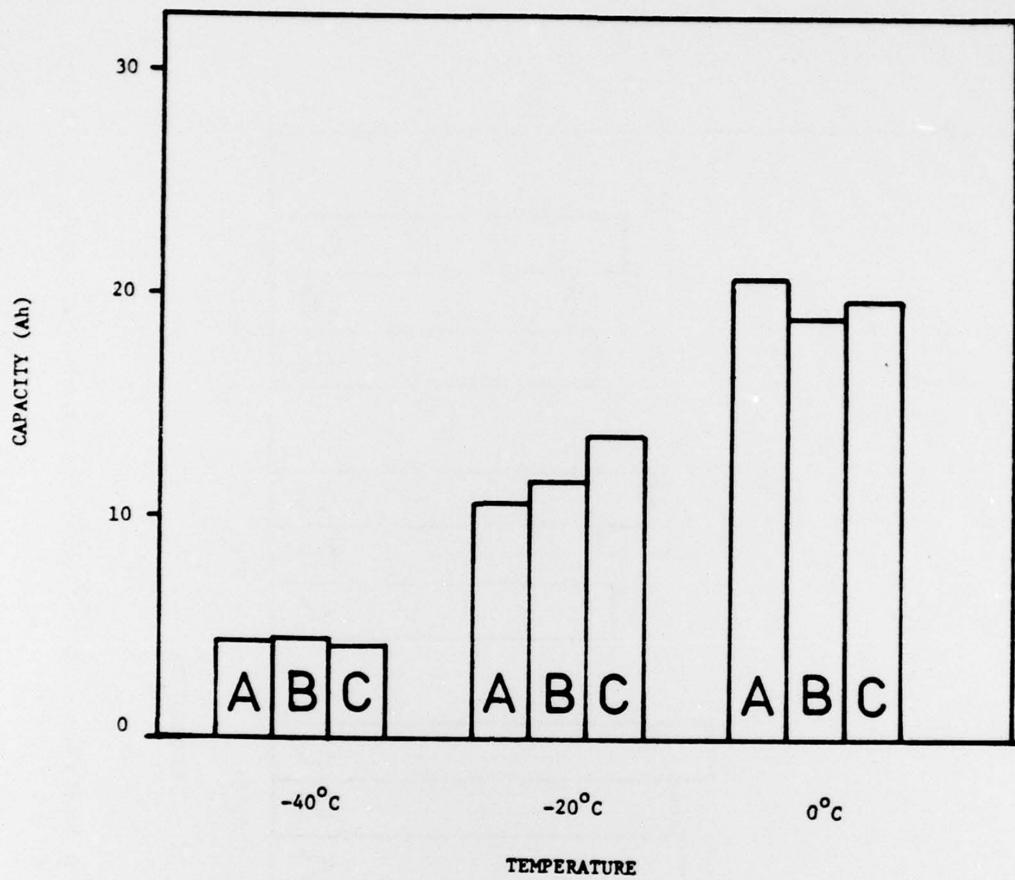


*Fig. 5. Capacity of each battery type at different temperatures*
*A: Red Camel*
*B: Gould $Ca^{+}/Ca^{-}$*
*C: Gould $Sb^{+}/Ca^{-}$*
*Cranking current: 210A*
*Cut-off voltage: 6V*
*Fully Charge batteries.*

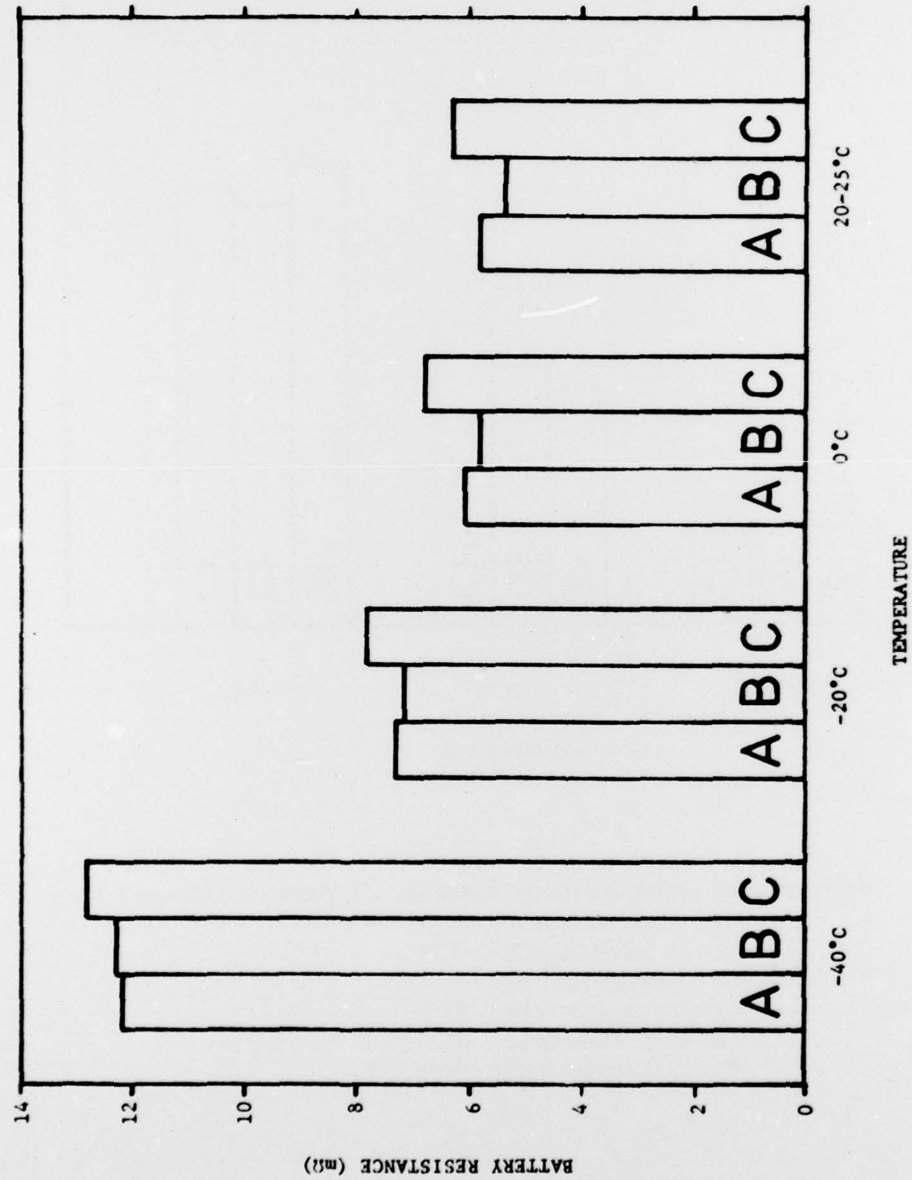


*Fig. 6. Internal battery resistance at different temperatures. More details are given in Fig. 5.*

## THE INFLUENCE OF THE CRANKING CURRENT

As illustrated in Fig. 7, the capacity decreases as the cranking current increases. In this Figure, the capacity values corresponding to 3C and 4C cranking rates at RT, 0°C, -20°C are represented for the three different batteries. For the Red Camel batteries, the loss in capacity is 24% at RT and 16% at 0°C when the current is increased from 3C to 4C. Similar losses in capacity were recorded for the two Gould batteries.

## THE ACID WARM UP

The acid consumption reaction, the Joule's effect and, possibly, the formation of ice (3, 4) generate heat during the discharge periods and the whole battery tends to warm up (5). As previously observed for the military battery type BB 248/U (5), the temperature of the battery increases almost linearly with time (Fig.8). In addition, $\Delta T$ values, defined as the difference between the initial temperature and the temperature one minute following the completion of the discharge, increase with the duration of the cranking period as illustrated in Fig. 9. In the case of a Red Camel battery discharged at 192A, the increase in $\Delta T$ with increasing duration of discharge is between 1 and 2 C°/min. (Fig. 9). In addition, the values are approximately the same at 3C and 4C cranking rates (Fig. 9 and 10).

It should be noted that the magnitude of the acid warm-up depends on the type of battery. It is observed $\Delta T$ is larger for the Red Camel which is followed by the Gould Sb+/Ca- (Fig. 11). For example, $\Delta T$ for the Red camel battery is 13C° compared to only 6.2C° for the Gould Ca+/Ca- at an ambient temperature of 0°C. These different $\Delta T$ values may not be attributed to the duration of the cranking period or to the Joule's effect since the capacity values at 210A (cranking current) are approximately the same (Fig. 5) and the IBR values (Fig.6) are very similar. The heat generated should be mainly absorbed by the acid and, therefore, one would expect the smaller the amount of acid, the higher the warm up. This however, is not what was observed (Table 1 and Fig. 10) and suggests that the difference in $\Delta T$ values may be attributed to the different design features of the batteries. The low number of cells that has been tested does not allow us to draw any final conclusions in connection with this matter.

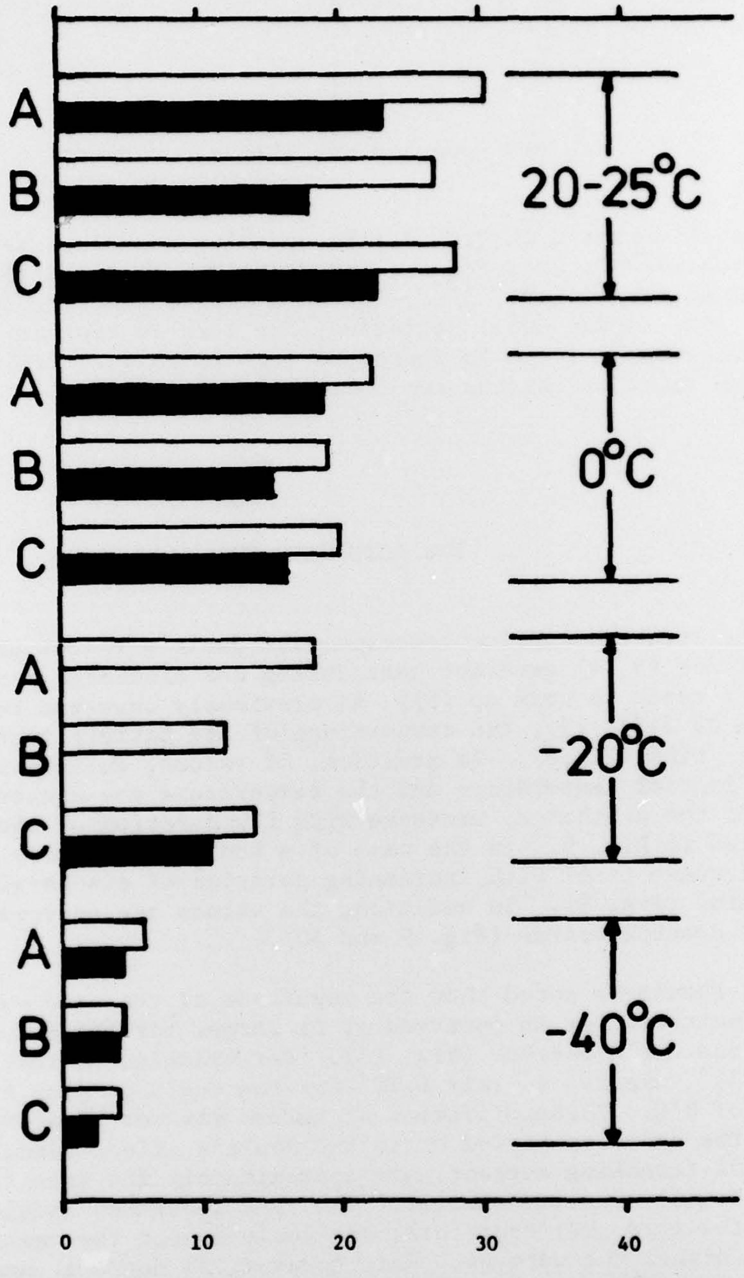


*Fig. 7. Capacity of the batteries at different temperatures and cranking rates (more detailed in Fig. 5). White bars: 4C. Black bars: 4C.*

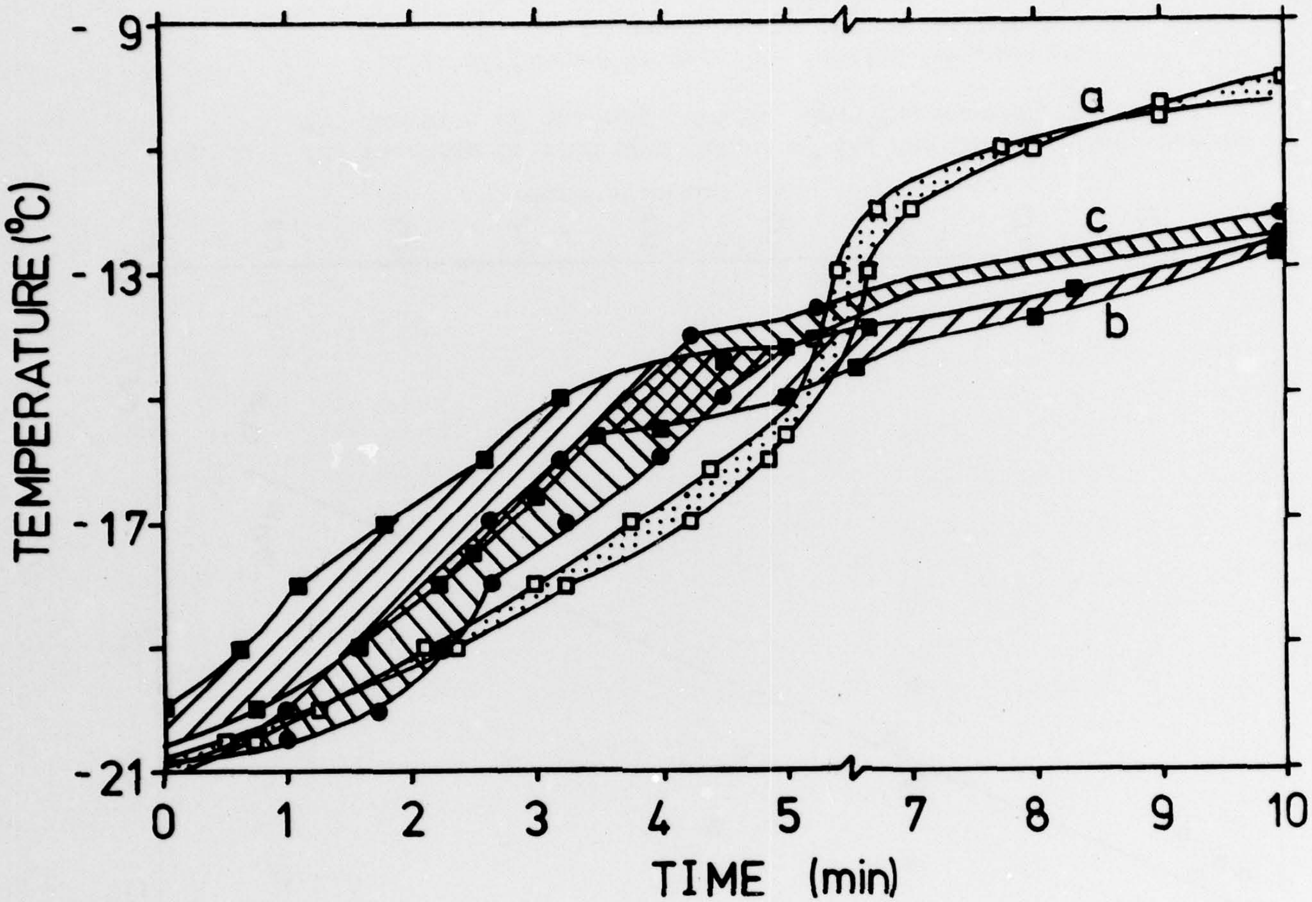


*Fig. 8.* *The battery acid temperature versus duration of the cranking period. Initial temperature: -20°C. Discharge rate: 3C.*

*a: Red Camel*
*b: Gould $Ca^+/Ca^-$*
*c: Gould $Ca^+/Ca^-$*

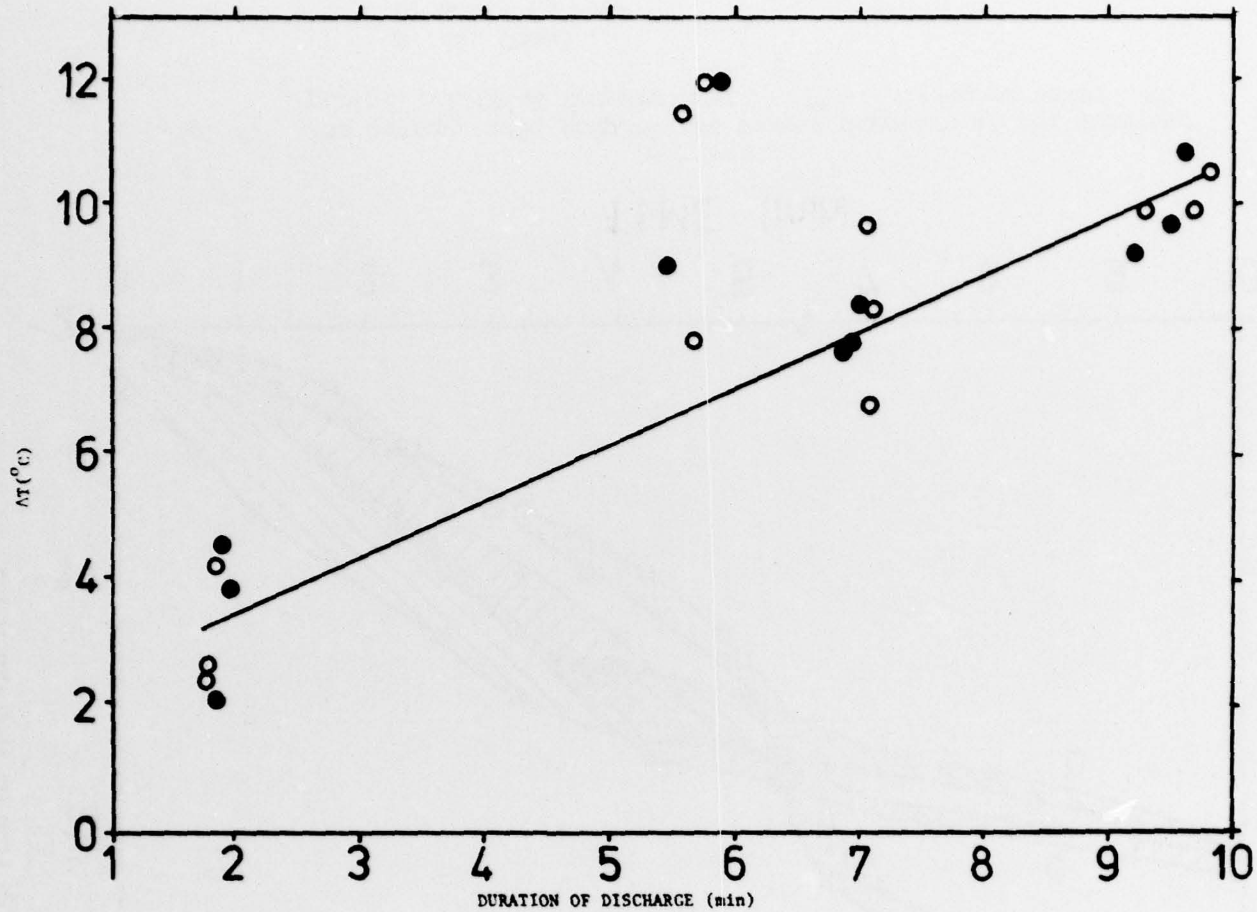


*Fig. 9. The increase in acid temperature of the Red Camel battery versus the duration of cranking period. Cranking current: 192A (3C).*

*ΔT: difference between the initial temperature and the temperature one minute following the completion of the discharge.* **o,● refer to two samples of the same battery type.**

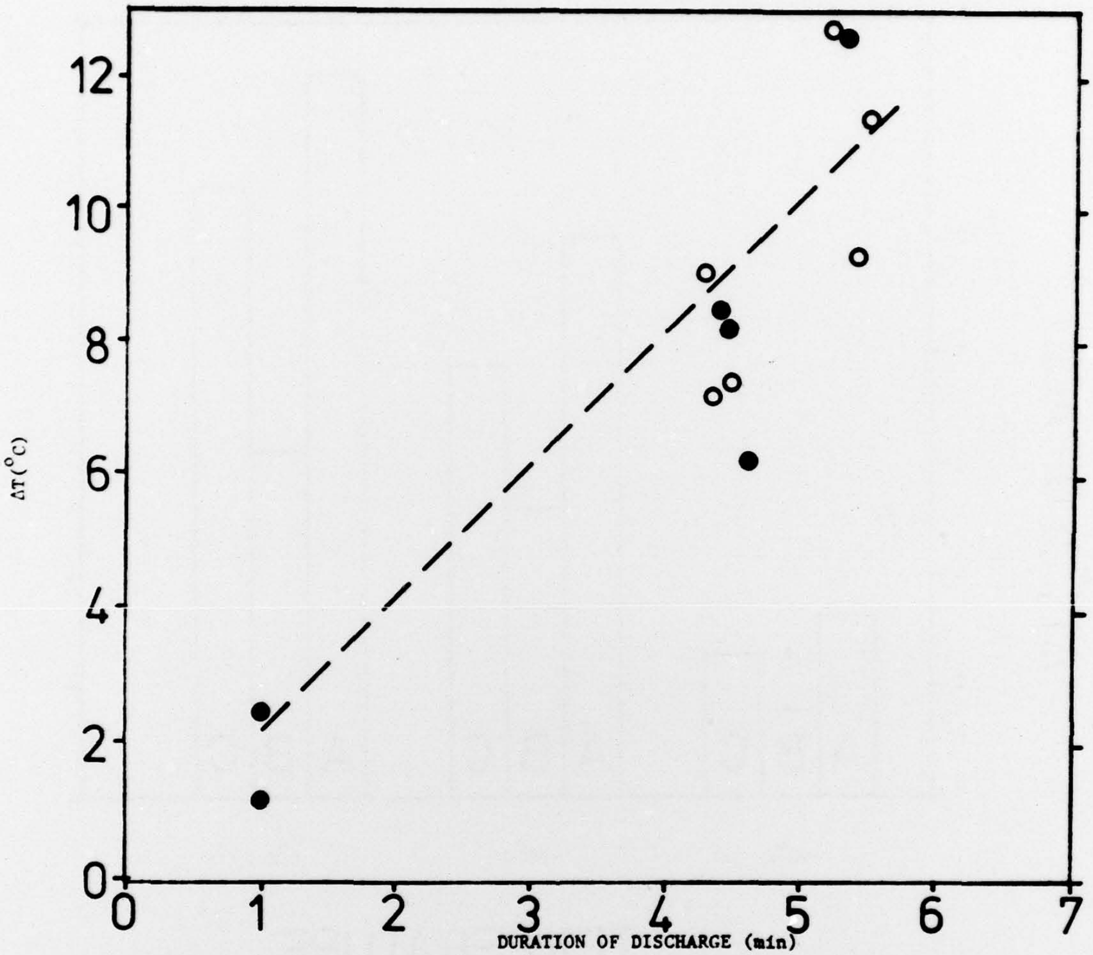


*Fig. 10. The increase in acid temperature of the Red Camel battery at 4C. The experimental conditions are given in Fig.9 except for the cranking current.*

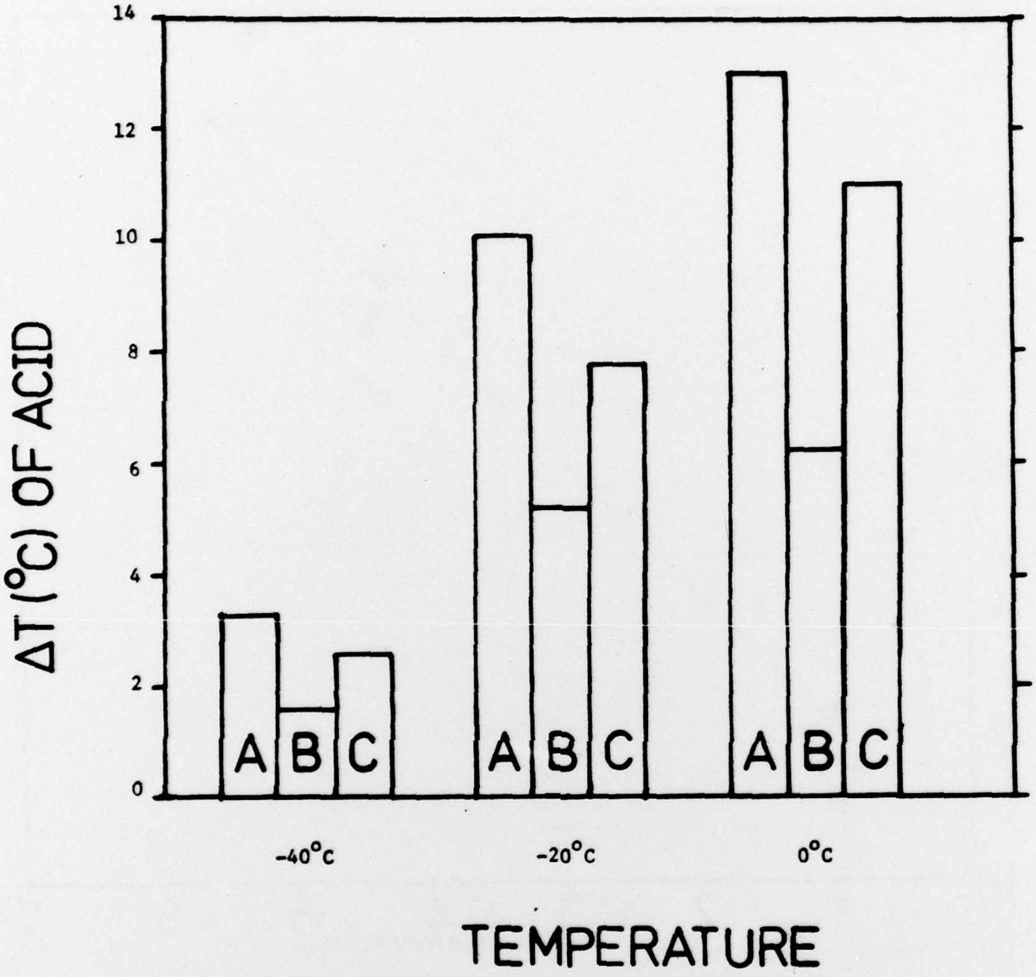


*Fig. 11. The increase in acid temperature resulting from a 210A discharge*

*A: Red Camel*
*B: Gould $Ca^+/Ca^-$*
*C: Gould $Sb^+/Ca^-$*
*The batteries were initially fully charged at RT.*

## CONCLUSIONS

1. At high cranking rates, between 3C and 4C, the behaviour of all of these batteries is very similar. The only significant difference is related to the increase in battery temperature resulting from a discharge.

2. For one given battery, the capacity and the voltage plateau decrease as the cranking rate increases.

3. The warming of the acid electrolyte during periods of cranking is about 1 to 2C°/min of discharge when the cranking rate is 3-4C.

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